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**INTERNATIONAL EXCHANGE OF GENETIC RESOURCES, THE
ROLE OF INFORMATION AND IMPLICATIONS FOR OWNERSHIP:
THE CASE OF THE U.S. NATIONAL PLANT GERMPLASM SYSTEM**

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ABSTRACT

Changing perceptions of resource ownership have altered international exchange of genetic resources. After summarizing the role of genebanks and issues related to property regimes, this paper presents an empirical study of one of the largest national genebanks, the U.S. National Germplasm System. The demand for its genetic resources appears to be substantial, both domestically and internationally. Utilization rates are higher than suggested by past studies. The role of information in enhancing the usefulness of NPGS resources is explored with an econometric model that indicates that accompanying data make germplasm more useful. U.S. requestors account for most of the germplasm demanded, but developing countries appear to make greater use of these resources, proportionally, in terms of overall usefulness, secondary sharing, and the presence of useful data. Demand for public germplasm is likely to increase in the future, particularly from developing countries.

Key words: Crop genetic resources, genebanks, germplasm collection, genetic resource management, developing countries.

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Kelly Day Rubenstein² and Melinda Smale³

1. INTRODUCTION

All agricultural commodities and the varieties used in modern production systems descend from a vast array of wild and improved genetic resources from around the world. Agricultural production depends on continuing infusions of genetic resources to ensure yield stability and sustained growth.

Each country relies on other countries for access to genetic resources (also called germplasm) that cannot be found within its own national boundaries. The exchange of germplasm among countries has a long history, and became routine as modern agriculture came into being. The gains from exchange of germplasm are the combinations of genes that are not possible otherwise; almost every plant species of major economic importance to the U.S., for example, has come from or been improved with germplasm from elsewhere. Even countries that served as “centers of origin” as certain crops were domesticated rarely have the broad spectrum of germplasm they desire (Crosby 1986). The extent to which both rich and poor countries have benefited from the exchange of germplasm has been documented (Fowler, Smale, and Gaiji 2000; Gollin, Smale, and Skovmand 2000).

¹ The views presented are the authors', and do not necessarily represent those of the Economic Research Service or the U.S. Department of Agriculture.

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While genetic material historically has been collected and exchanged relatively freely, over time interest has grown in systems based on national ownership. Some argue that national ownership would both provide incentives for conservation of genetic resources *in situ* (resources found in the place in which they naturally occur) as well as address economic inequities among those who supply and demand germplasm (Mooney 1979, 1983; Christensen 1987; Kloppenburg 1988; Brush 1992). Others are skeptical (Acharya 1991; Reid 1992; Brush 1994). Debates have both fueled and complicated the development of international agreements addressing genetic resources.

There is also disagreement about how many resources should be devoted to germplasm conservation and utilization. With heavy competition for funding, funding for genebanks generally has not kept pace with the costs of maintaining collections. Sparse, and incomplete estimates of the value of germplasm and levels of use, which reflect the inherent difficulty of assigning market values to what is primarily a non-market resource, have complicated the debate over funding for genebanks (summarized in Smale and Koo 2000).

The findings reported here shed light on policy issues related to the use of genetic resources distributed by genebanks, the role of information and their ownership. In 1997, Wright identified four fundamental deficiencies in information about genebanks: 1) who uses the genebanks; 2) why users want germplasm; 3) what kind of germplasm is used; and 4) what characteristics are users seeking. The data compiled here address these questions for one of world's largest national genebank, the U.S. National Plant Germplasm System.

The following section briefly explains the role of genebanks and the genetic resources they conserve in the agricultural production process, summarizing the issues related to property

regimes. Data collection methods are then described. Findings are then reported, and policy implications are discussed in the final section.

GENETIC RESOURCES IN AGRICULTURAL PRODUCTION

In hunter-gatherer societies, the gatherers collected what we now consider the wild relatives of crops. At some point, people began to deliberately cultivate certain plant species. Before the development of modern varieties, farmers cultivated only landraces. Landraces are varieties of crops that evolved and were improved by farmers over many generations, without the use of modern breeding techniques. In many parts of the world, this process continues today. These varieties are typically more genetically heterogeneous than lines and finished varieties developed by breeders and because they are adapted locally to specific environments, they may contain unique genes or gene complexes.

The pace of improvement accelerated as modern breeding techniques were developed that facilitated selection of specific desirable traits. Within most types of crops, breeders have crossed different parental material and selected traits resulting in cultivars with high yields, better quality, resistance to pests and diseases, tolerance to non-biological stresses (such as drought), or other goals. Generally, they prefer to work with existing cultivars, or advanced breeding materials (sometimes called “elite materials”), because these adapted sources of material are relatively easy to work with. Because pests and diseases evolve over time, breeders continually need new and diverse germplasm from outside the utilized stock, sometimes using wild relatives and landraces, to find specific traits to maintain or improve yields (Duvick 1986).

Plant breeders often rely on landraces or wild relatives as a last resort, because they generally carry other less desirable genes with them and can be difficult to incorporate into high yielding cultivars (Goodman 1990, Cox 1991). But when used, genes from these materials have

"often had a disproportionately large and beneficial impact on crop production" (Wilkes 1991). Some breeders also seek and use traits and information from "genetic stocks", which include mutants and other germplasm with chromosomal abnormalities. The plant breeding process is a complex and continual one, in which diverse genetic resources remain a critical input.

GENETIC RESOURCES IN GENE BANKS

Genetic resources have strong public goods characteristics, i.e. they are generally nonexcludable and in many cases non-rival (Brown 1987; Brown and Swierzbinski 1985; Frisvold and Condon 1994; Sedjo 1992; Reid 1992; Swanson 1996). Historically, intellectual property protection has been relatively weak for biological innovations and thus has presented a limited mechanism for exclusion. Furthermore, the usefulness of particular genetic resources is highly uncertain, and time horizons for developing genetic resources are long. The inability of private investors to appropriate gains from biological resources has been associated with insufficient incentives to preserve genetic resources. Thus, the public sector has played a pivotal role in the conservation of these resources.

Public germplasm management focuses on a set of activities: acquisition, preservation *ex situ*, characterization, documentation, evaluation, enhancement, and distribution of genetic resources (Clark et al 1997). The first, acquisition, involves gathering germplasm from the field, the wild, or from other genebanks. Preserving germplasm *ex situ* (outside its natural habitat) includes general maintenance of germplasm and the use and development of technology to improve the preservation process (and documentation maintains information that is collected about the accessions along the way). Characterization and evaluation focus on the nature and qualities of germplasm accessions. Enhancement seeks to use germplasm to create superior

crops and livestock breeds through breeding.⁴ Distribution activities are what bring the materials, at whatever stage, to the end-users of germplasm. Public resources are allocated among these different activities.

POLICY ISSUES

Historically, the relatively free collection and exchange of germplasm relied heavily upon developing countries as providers of raw genetic material to public germplasm repositories. Developing countries, as a group, are frequently the source of such materials because they often lie in geographic centers of diversity and because they continue to use more landraces. Some developing countries argue that the system of unrestricted access to germplasm without compensation was inequitable because private breeders sell their modern varieties, which descend from the landraces and wild relatives originally developed by farmers (Fowler, 1991). Observers disagree about whether foregone earnings from sales of raw genetic material by lower-income countries are compensated for by maintaining free access to public germplasm and lower world food prices (Shands and Stoner 1997). Even the terms “unimproved” germplasm or “raw” germplasm became a source of tension. These materials are rarely of use in modern production systems until they have been selected and combined, with considerable additional investment. However, from another perspective, they are the products of many generations of effort and expertise by the farmers that grew, selected, and conserved them. Those who hold this latter perspective maintain that indigenous farmers have the right to some return on the use of these resources in commercial varieties, and also that such rewards would increase the incentives for conservation (see Lesser, 1997).

⁴ A comprehensive survey of public and private plant breeding research by Frey (1996) showed that USDA’s Agricultural Research Service (ARS) concentrates most of its research on long-term pre-breeding activities associated with plant breeding research and genetic enhancement. The private sector devotes most of its resources to short-term varietal development.

Against this backdrop, international agreements have sought to improve preservation of genetic resources and fairly allocate returns to their benefits. The Commission on Plant Genetic Resources (now the Commission on Genetic Resources for Food and Agriculture) was established to address such issues in 1983, under the auspices of the Food and Agricultural Organization. The Commission developed a non-binding treaty to govern the exchange of genetic resources, called the International Undertaking. The first resolution called for free exchange of all germplasm, including improved varieties protected by intellectual property mechanisms. As a result, most developed, and several developing countries refused to agree to the Undertaking (Artuso, 1998). Negotiations on the specifics of the Undertaking continued for some time, but efforts to implement it widely stalled.

A major development in the quest for ownership of genetic resources was the development, signing and ratification of the U.N. Convention on Biological Diversity (CBD).⁵ Originally, the CBD was focused on the preservation of non-agricultural biodiversity, particularly resources for pharmaceutical products. To assure equitable returns for the use of native resources (and to spur their conservation), the CBD granted sovereign rights to genetic resources (Article 15:1). This, of course, had implications for the exchange of "unimproved" genetic resources and landraces between countries. For example, the Convention can be interpreted to allow countries to sell unimproved genetic resources and landraces, or demand royalties for their use.

A desire to bring the International Undertaking into conformity with the CBD led to renewed negotiations for a system directly addressing crop genetic resources. Negotiators were seeking a treaty that would 1) mandate conservation of plant genetic resources, 2) assure equitable sharing of the benefits created by using these resources, and 3) establish a multilateral

⁵ The U.S. is a signatory to the CBD, but has not yet ratified it and thus, is not a party to the Convention.

system to facilitate access to plant genetic resources. Eventually, negotiations led to the adoption of the text of the International Treaty on Plant Genetic Resources for Food and Agriculture in November of 2001. The new International Treaty entered into force on June 29, 2004, and governs international exchange of germplasm for a specified set of 34 crops and 29 forages among countries participating in the multilateral system (rather than the bilateral approach suggested by the CBD). The treaty has not been implemented at the time of this writing because it must follow terms of access described in a standard Material Transfer Agreement that thus far have not been decided (the U.S. has not yet ratified the Treaty).

A yet-to-be determined proportion of monetary benefits will be paid to a trust account managed by the Governing Body, rather than direct payments to providers, as the CBD is generally interpreted to suggest.⁶ Thus, while countries retain ownership of these resources, they agree to share them with other participants in the multilateral system without direct compensation. However, the current vague terms of the Treaty and its limited scope suggest that the controversies surrounding the ownership of genetic resources are likely to persist.

2. DATA SOURCES

Many national collections, especially those found in the developing world, do not possess the resources to digitize information regarding their distributions or distribute relatively small volumes of germplasm samples. We use the U. S. National Plant Germplasm System (NPGS) as a case study because of the documentation maintained by its curators and the volume of material

⁶ International agreements specifically concerning intellectual property rights also have implications for genetic resource conservation. The World Trade Organization's (WTO) agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS) may affect the exchange of germplasm through its provisions. To join the WTO, countries must commit to implementing a system protecting intellectual property for plant genetic resources, and the WTO has the ability to levy sanctions for noncompliance.

it distributes both nationally and internationally. The U. S. NPGS, the multi-institution system that manages publicly-held germplasm in the U.S.,⁷ is one of the largest national genebanks in the world, holding over 450,000 accessions (GAO 1997). The global importance of the collection is illustrated by comparing its distribution volume with that of other genebanks. The CGIAR centers hold a large proportion of the total accessions conserved globally in trust. One of these centers, the International Center for Maize and Wheat Improvement, distributed 20,540 samples of maize and 39,770 samples of wheat from 1987 to 1998. During a similar time period (1990 to 1999), the NPGS sent out 30,493 samples of maize and 154,962 samples of wheat internationally. In all, NPGS germplasm was sent to requestors in 191 countries and 45 territories, departments, or commonwealth associations outside the U.S (Appendix). Because the NPGS has such extensive holdings, distributes so much germplasm, and serves a large international community, data on requests for NPGS germplasm samples generate both a national and an international profile of genebank use.

Data presented here were compiled from two sources. The first was summaries of germplasm samples distributed by NPGS from 1990 to 1999 for the 10 crops, provided by the U.S. National Germplasm Resources Laboratory, which manages the system's database (the Genetic Resources Information Network) and coordinates plant exploration and international exchange programs. The second was developed by gathering information directly from users of NPGS samples. Nearly 4,000 requests were made for germplasm samples of these 10 crops from 1995 to 1999, though several names appeared more than once with different crops. A five-year period was chosen, in light of Widrechner and Burke's (2003) findings on the importance of

⁷ The NPGS system includes national-level centralized facilities (for coordination, quarantine, and long-term seed storage) as well as a number of collections throughout the country. All available germplasm is provided to people free of charge, upon request. Special permission is required to fill germplasm requests from countries without diplomatic relations with the U.S.

using more than a single year of germplasm distribution data because of short-term fluctuations. Each requestor was sent a letter explaining the purpose of the study and a form that asked for information about the recipient's experiences with NPGS during the past five years.

The International Plant Genetic Resources Institute (IPGRI) of the Consultative Group on International Agricultural Research (CGIAR) conducted the international portion of the study. The information from US users was collected by Auburn University. Here, the Economic Research Service of USDA and IPGRI have combined the two sets of responses for joint analysis. Among the combined set of respondents, 35 percent provided usable information. Response rates by crop ranged from 17 to 45 percent, with the lowest response rate in squash and the highest in wheat. For cotton, rice, sorghum and squash the number of responses was small for purposes of statistical analysis. Overall, response rates among international and US requestors were similar. However, among international respondents, the response rate was nearly twice as high in developed and transitional economies of the former Soviet Union and Eastern Europe as in developing countries.

Because respondents reported the number of germplasm samples they received, we can analyze the information either by respondent or by germplasm sample. Both approaches are employed in this paper, depending on which is more appropriate for the analysis.

3. FINDINGS

NPGS USERS

NPGS' in-house distribution figures can be used to create a profile of its user community. The majority of NPGS germplasm was sent within the U.S. Between 1990 and 1999, 74 percent of germplasm samples were distributed to U.S. requestors. Of the 26 percent of samples distributed internationally, about 12 percent were sent to developing countries. Another 10 percent were sent to other developed countries, and about 4 percent of samples were distributed to the transitional economies of the former Soviet Union and Eastern Europe.

Distribution data also offer information about the types of institutions that make use of NPGS germplasm. The NPGS uses four categories of institutional affiliation: private, public, other non-profit and unaffiliated. Most NPGS germplasm went to public institutions: 58 percent of samples went to government, university, or other publicly-funded research and development institutions. Requests from publicly-funded institutions represented 74 percent of germplasm distributed within the U.S., while other non-profit institutions dominated among non-US recipients of NPGS samples. While accounting for only 22 percent of samples over all, these non-profit, non-governmental organization received about 80 percent of the samples sent outside the US. Commercial recipients received 18 percent of all samples sent by the NPGS. This was surprising, because generally private breeders are thought to rely primarily on their own collections (Mann 1997; Wright 1997), therefore their use of genebanks is believed to be limited.

⁸ The role of commercial institutions is far more prominent in the U.S, accounting for almost 23

⁸ However, in his survey of U.S. breeders, Duvick (1984) found that private breeders make use of all germplasm sources, a finding confirmed by the NPGS data.

percent of samples distributed within the U.S. In contrast, 6 percent of the samples NPGS sent abroad in the past decade were shipped to commercial requestors (Table 1).

Table 1--Seed samples distributed by the National Plant Germplasm System, 1990-1999 by type of institution and country classification

Income and location	Commercial		Public		Other non-profit		Unaffiliated individual		All institutions	
	No.	%	No.	%	No.	%	No.	%	No.	%
U.S.	104863	23	338689	74	4805	1	10208	2	458565	100
Other developed countries	2294	4	9799	17	45997	78	642	1	58732	100
Developing countries	4793	6	10287	13	62144	80	292	0	77516	100
Transitional economies	83	0	4201	16	22127	84	14	0	26425	100
All countries	112033	18	362976	58	135073	22	11156	2	621238	100

Notes:

Includes 10 major crops: barley, beans, cotton, maize, potato, rice, sorghum, soybeans, squash, and wheat

Country classification is shown in the Appendix.

Public institutions include all government organizations, public universities, genebanks and genetic resource units.

Source: National Germplasm Resources Lab, USDA

USE OF NPGS GERMPLASM

Type of Germplasm Requested

The type of germplasm distributed suggests a user community that is actively involved in plant breeding. NPGS data on distributions reveal that cultivars were the germplasm type most commonly requested during the 1990s, accounting for 47 percent of distributed materials. Cultivars are cultivated varieties, which are suitable for planting by farmers, including both those that are recently developed and "obsolete" cultivars that are no longer grown. Breeders conducting highly sophisticated breeding request this category of material, as well as do those looking only to adapt varieties with good performance. Landraces are the second most commonly requested type of germplasm, perhaps more surprisingly (19 percent). The use of landraces generally suggests a fairly complex search for traits, given the difficulty of incorporating them into final varieties.⁹ Another 12 percent of the materials distributed were advanced breeding materials, which the breeders use to produce new cultivars. These materials, like the wild and weedy relatives that make up 10 percent of the materials the NPGS distributes, would likely be used in an active breeding program rather than one that simply seeks finished varieties.

Survey responses indicate some differences in requests by germplasm types across U.S. and categories of international users.¹⁰ Users in developing and transitional economies were more likely to request advanced breeding materials than those in developed and transitional economies, while those in either other developed or transitional economies were more likely to

⁹ The desirable genes found in landraces often need to be separated from those that have deleterious effects on performance. Conventional breeding separates traits through a laborious process, but transgenic methods may make this process easier.

¹⁰ Different germplasm categories are used in the NPGS distribution data and in the survey. For those categories which are the same (e.g., cultivars), the percentage of germplasm respondents report that they requested differs somewhat from the percentage distributed by NPGS.

request landraces. More requests for finished cultivars originated in transitional economies. Demand for genetic stocks was higher only among breeders in developing countries (36 percent). Proportionately higher numbers of requests for advanced material and genetic stocks suggest that developing countries have active experimental breeding or research programs and are, as a group, not simply seeking finished varieties for determining local adaptation and possible direct use (Table 2).

Table 2--Requests for NPGS germplasm by type and country classification of respondent

Country classification	Percentage of respondents requesting germplasm type				
	Cultivar	Advanced Material	Genetic Stocks	Landraces	Wild Relatives
U.S.	60	16	24	25	23
Other developed countries	46	16	24	31	31
Developing countries	51	29	36	21	18
Transitional economies	59	30	22	28	33
	**	**		**	
All	56	18	25	26	24

Note: Requests (rows) sum to more than 100 percent when requests of more than one material type are made.

** Pearson Chi-squared tests (two tails, significance level=0.01) show significant differences in percent requesting material type by country status.

Source: Survey conducted by the International Plant Genetic Resources Institute and Auburn University, based on data provided by the National Germplasm Resources Lab, USDA

Purpose of request

The survey data suggest that two-thirds of users (62 percent) sought specific traits in the samples they requested. This was particularly true for those users located in the U.S. The second most frequently cited reason for requesting germplasm is to conduct basic research (14 percent). Breeding or prebreeding was noted by respondents as the intended purpose for 13 percent of requests. Germplasm acquisition was the reason given by respondents for only 11 percent of requests (Table 3).

Table 3--Purpose of requests for NPGS germplasm samples by respondent's country classification

Country Classification	Breeding or Prebreeding	Evaluation for Specific Traits	Basic Research	Add to Collection	All requests
	%	%	%	%	%
U.S.	12	68	12	8	100
Other developed countries	17	32	35	16	100
Developing countries	15	45	15	25	100
Transitional economy	14	39	26	22	100
Total	13	62	14	11	100

Note: Transitional economy refers to countries in the Former Soviet Union or Eastern Europe.

Source: Survey conducted by the International Plant Genetic Resources Institute and Auburn University, based on data provided by the National Germplasm Resources Lab, USDA.

Traits sought

Of the traits respondents sought to evaluate in the germplasm samples, biotic resistance or tolerance was by far the most frequently cited (37 percent of samples), regardless of the type of germplasm. Biotic stresses come from other living things, specifically herbivores and pathogens. Breeders search for traits that strengthen resistance against these threats (Table 4).

Table 4--Traits sought by respondents

Material	Average Percent of Samples Used to Search for Trait			
	Abiotic	Biotic	Yield	Quality
	Tolerance	Resistance or Tolerance		
Cultivars	13	31	15	17
Advanced breeding material	13	40	25	21
Landraces	16	38	13	20
Wild relatives	14	38	3	14
Genetic stocks	14	38	3	14
			**	**
All materials	14	37	12	17

Row totals may exceed 100 if accessions are used to search for more than one trait.

** Pairwise t-tests (two tails, significance level=0.05) show significant differences by germplasm type in average percent of samples requested to search for yield and quality.

Source: Survey conducted by the International Plant Genetic Resources Institute and Auburn University, based on data provided by the National Germplasm Resources Lab, USDA.

Resistance to abiotic stresses was sought less frequently than resistance to biotic stresses (14 percent of samples). Abiotic stresses arise from the environment in which the plant operates: particularly temperature and water availability; but also light intensity, and organic and inorganic pollutants. Examples of abiotic resistance that a breeder might seek include drought resistance and the ability to flourish in high-saline soil.

Quality traits were the object of evaluation in 17 percent of samples requested by all respondents. Examples of quality traits include oil and sugar contents (which may influence the range of uses of a crop, or its taste), seed weight, and nutritional content.

Yield traits, in this context, refer to expected yield independent of particularly stresses or yield potential as compared to actual crop yields under farmer-managed field conditions. A significant proportion of advances in crop yield have been attributable to improving pest resistance and tolerance to other stresses as compared to gains in yield potential (Adusei and Norton 1990). It is not surprising, therefore, that yield was the focus of only 12 percent of materials evaluated for a specific trait.

Estimates of Usefulness of Materials

While this study relies on current use in a breeding or research program, it is only one source of value associated with materials conserved in genebanks. Moreover, materials may be useful in the future of the breeding cycle, rather than just when they are first received, and may be incorporated into research outcomes multiple times by different users. Any estimates of current use therefore underestimate actual use, and actual use underestimates value.

Despite these caveats, the survey data clearly suggest higher levels of use than had been suggested by past studies (Goodman, 1990). Requestors were asked how many of the materials they received over the past five years had been found “useful,” and in what way. They reported that 9 percent of samples had already proved useful in a breeding program. Twenty-seven

percent of germplasm samples were still being evaluated and 14 percent of materials had proven to be useful in other ways. Respondents found 50 percent of the materials not useful.¹¹ (Table 5)

Table 5--Estimated utilization of NPGS germplasm samples, by country classification of requestor

Country classification	Used in breeding program	Still being evaluated	Useful in other ways	Not useful	Total
Percentage of samples					
U.S.	8	23	14	56	100
Other developed	6	39	29	26	100
Developing	17	53	8	22	100
Transitional economy	7	23	17	53	100
All countries	9	27	14	50	100
Estimated number of seed samples					
U.S.	18,276	53,312	32,603	132,571	236,762
Other developed	1,212	8,276	6,081	5,477	21,045
Developing	5,508	17,048	2,591	7,005	32,151
Transitional economy	709	2,384	1,791	5,475	10,359
All countries	25,705	81,019	43,066	150,527	300,317

Source: Survey conducted by the International Plant Genetic Resources Institute and Auburn University, data provided by the National Germplasm Resources Lab, USDA

Country classification was clearly a factor in the usefulness of the NPGS materials. Developing country respondents said that 17 percent of NPGS materials had already proved useful in a breeding program, compared with 6 percent of materials sent to developed country respondents and similar percentages reported by U.S. respondents and those in transitional economies. The percentage of materials still being evaluated was also highest among developing countries. Over half the materials were still being evaluated by developing country respondents,

¹¹ These rates of usage are substantial higher than Goodman's (1990) estimate that the number of germplasm accessions useful for intensive breeding is almost always less than 5%, and generally less than 1%.

considerably more than the 23 percent being evaluated by U.S. and transitional economy respondents, (or the 39 percent materials still being evaluated by non-U.S. developed country respondents). Developing countries respondents had the lowest percentage of materials not found useful (22 percent). (Developed country respondents outside the U.S. found the highest percentage of materials useful on other ways (29 percent).) Overall, these results portray respondents in developing countries as finding the NPGS materials highly useful: they incorporated them in breeding programs and continued to evaluate them at much higher rates than did respondents located in higher income, industrialized economies. Combining the respondents' data with the NPGS distribution data allows us to generate an estimate of the actual numbers of germplasm samples used during 1995 to 1999 for the ten crops¹² considered (Table 5). An estimated 25,700 samples were used in a breeding program, by all NPGS recipients. Considerably more were still being evaluated (81,000 samples). Approximately 43,000 samples are estimated to have been useful in other ways. Thus, a considerable volume of material has been used in a breeding program, found worthy of further investigation, or been useful in other ways. While certain materials may never be used, the number of samples estimated to be in use seems to counter the assertion that the material in the bank is rarely used (Wright, 1997).¹³

Secondary Use

The NPGS germplasm can be shared with other researchers, both in and beyond the original requestors institution. Approximately 11 percent of samples received by respondents were shared with others at the respondent's institution. Respondents shared 13 percent of germplasm samples with others at another institution. Respondents from private companies were more likely to share their samples within their own institution, which was the case with 36

¹² The ten crops are barley, beans, cotton, maize, potatoes, rice, sorghum, soybean, squash, and wheat.

¹³ Landraces and wild relatives are some of the most difficult material with which breeders work, and whether breeders use them with any frequency has been questioned (Cox, 1991).

percent of the samples and least likely to share outside their institution (3 percent of the samples received). Within government and university institutions, the situation is opposite that of private companies, though not as pronounced. Respondents shared only 9 percent of the samples received within their own institution, but shared 14 percent with other institutions. Respondents from non-profit institutions were most likely to share the samples they received within their institution (50 percent) and as well as outside it (15 percent). ¹⁴

Differences in secondary use also were found with country classification. Developing country respondents were more likely to share the NPGS materials, particularly within their institution. Developing country respondents shared 24 percent of the materials they received with others at their institution, and 17 percent of materials with others at outside their institutions. (Non-U.S. developed and transitional economies shared their materials with others at about the same rate). Overall, while developing country requestors received about 12 percent of the materials distributed by the NPGS, we estimate that these requestors were responsible for about 18 percent of the secondary use of NPGS materials. ¹⁵

FUTURE DEMAND

While the volume of NPGS materials distributed and used has been substantial, a key question for policy makers and genebank managers is the future demand for genetic resources stored in the NPGS collections. Requestors were asked whether they expected their use of

¹⁴ Looking at sharing according to the respondent's crop of interest, there are some similar patterns with respect to the competitive nature of the breeding practices associated with that particular crop. Maize respondents shared 16% of their samples with others at their own institution (slightly more than the overall average). However, they shared only 6% with scientists at other institutions. Maize breeding is conducted primarily by the private sector, and there is competition for market share. Within wheat, respondents shared 12% of samples within their institution (close to the average samples shared across crops). However, 30% of samples were shared with others outside the respondent's institution. Wheat is a crop that is bred primarily by public breeders (outside of Europe), hence market competition is not a major concern. Soybean, a crop that has become increasingly of interest to private companies, showed low levels of samples shared by respondents.

¹⁵ Unfortunately, an estimate of total samples shared cannot be generated because the numbers of samples shared with people inside and outside the respondent's institution cannot be simply added together (because the same samples may have been shared).

NPGS germplasm to increase, to stay the same, or to decrease. Nearly half the respondents expected their use of NPGS germplasm to stay the same (47 percent). Increased use was anticipated by about 39 percent of respondents. About 14 percent expected their use of NPGS germplasm to decrease. Overall, these results suggest that demand for NPGS resources will be increasing, though to what degree is unclear. Looking at respondents' institutional affiliation, within each category, the majority of respondents expect their demand to remain steady or to increase. The greatest expected increases are among genebank-based respondents (48 percent) and those at non-profit institutions (43 percent). The greatest decrease in use is expected for unaffiliated individuals (28 percent).

Future use of the NPGS showed pronounced differences by development status. 70 percent of respondents in developing countries expected to increase their use of the NPGS. Among all non-U.S. respondents, the percentage of respondents expecting to increase their use of the NPGS was higher than it was for U.S. respondents. Among transitional country respondents, 54 percent expected their future use of the NPGS to increase, as did 39 percent of respondents in non-U.S. developed countries. Developing country respondents also had the lowest rate of expected decreases in NPGS use: only 4 percent of respondents expected to make less use of the bank, compared with an average of 12 percent of all respondents.

THE ROLE OF INFORMATION

Two of the activities carried out by public genebanks are characterization and evaluation. Characterization is a detailed description of materials collected in the field that is part of the acquisition process (Clark et al. 1997). These descriptions, such as habitat, location, and taxon, are part of the "passport information" that is part of the plant's information record. Evaluation activities include studying the general make-up of the species (not looking for any specific trait).

Germplasm can also be examined for traits that are affected by the environment, such as temperature tolerance or pest resistance or morphological traits, such as size or taste. As researchers characterize and evaluate germplasm, they can create information that is useful to the breeding process. The information, in turn, also aids efforts to further evaluate germplasm.

Survey respondents stated that about 18 percent of the samples received had useful data for the trait of interest. Approximately 23 percent of samples came with other useful data. NPGS requesters were given the opportunity to describe the problems and benefits of the NPGS in their survey responses. When it came to the problems associated with the NPGS, respondents from all countries were uniform in citing problems with information more than any other.¹⁶ Thus, we hypothesized that there was a relationship between data about germplasm samples and their usefulness to respondents.

Another interesting factor was that developing country respondents were the most likely to state that their NPGS samples came with useful data for the trait of interest. These respondents said that 28 percent of germplasm samples had useful data for the trait of interest, the highest rate of all respondents, though generally non-U.S. respondents more often found that germplasm samples had useful data than U.S. respondents did. The percentage of germplasm samples with useful data for other purposes seemed to fall along opposite development status lines. Developed countries, including the U.S., were more likely to state that germplasm samples had useful data for other purposes, developing and transition country respondents were less so.

To explore systematically the relationship between the usefulness of germplasm samples and the accompanying data, we estimated a linear regression. The dependent variable is the

¹⁶ Specifically, they were asked to list the main benefits and primary problems associated with the NPGS. Not all respondents elected to offer additional information; therefore we can only present summary information as a percentage of the responses given. 39% of the problems cited by respondents concerned insufficient or inaccurate information.

percentage of samples that had proven useful to the respondent. “Useful” was defined as whether a sample had been used in the respondent’s breeding program, was still being evaluated¹⁷, or that a sample was characterized as “useful in other ways”.

The primary independent variable of interest was the percentage of samples with useful information. Respondents gave two answers for the usefulness of data question: the percentage of materials requested with useful data for the trait of interest and the percentage of materials with other useful data. While it was possible that the set of samples with useful data for the trait of interest and the set of samples with other useful data overlapped, correlation coefficients were within reasonable bounds and both variables were tested.

Differences revealed by the descriptive statistics led us to hypothesize that the development status of the country affected a range of factors related to the institutional and research environment of the respondent, and as a consequence, the relationship between the usefulness of samples and the presence of useful data. GDP per capita of the respondent’s country was used as a general proxy for these factors.¹⁸ Additional independent variables were nine fixed effects for the relevant crop, and five fixed affects for the profession as given by the respondent.

Respondents varied considerably in the number of samples requested. Some respondents worked with large breeding or research efforts, others requested one or two samples for small projects (which were sometimes unrelated to breeding or research, such as historical or artistic endeavors.) Because respondents who requested large numbers of samples were likely to differ

¹⁷ Given the lengthy process of plant breeding, if a sample was still being evaluated, it suggests usefulness, at least in the breeding process.

¹⁸ GDP dollar estimates for all countries (from U.S. Central Intelligence Agency, 2001) were derived from purchasing power parity (PPP) calculations rather than from conversions at official currency exchange rates. The PPP method uses standardized international dollar price weights, which are applied to the quantities of final goods and services produced in a given economy.

from respondents who requested only a few samples, we used a weighted least squares model, where the weight was the number of samples received by the respondent. Respondents who did not report receiving any samples were omitted from the model.

The regression results are shown in Table 6. The significance of the GDP per capita variable in the initial model pooling observations from all countries suggested that separate models by development status may be justified. The hypothesis that regression parameters were constant across country status was rejected with a Chow test.¹⁹

¹⁹ For the Chow test, $F_{\text{observed}} = 6.088$; $F_{\text{critical}}(18, 1208) \approx 1.95$ at the 1% level of significance

Table 6--Effects of accompanying data and other factors on use of germplasm samples

Variable	Parameter estimates			
	All countries	Developed countries	Developing countries	Transitional economies
(Constant)	.651**	.1.048**	.751**	.365*
GDP/capita	-7.061E-06**	-1.179E-05**	8.995E-06	-2.968E-05
% material with data for the trait of interest	.004**	.004**	.006**	.008**
% of material with other useful data	.004**	.004**	-.001	.004*
Crop = Barley	-.131**	-.119**	-.642**	-.172
Beans	.051)	-.022	-.196	.420**
Cotton	.291**	.325**	-.153	-.379
Maize	.040	.076	-.534**	-.200
Potato	-.093*	-.180**	-.021	-.092
Rice	.213**	.242**	-.108	-
Sorghum	.067	.032	-.234	.690
Soybean	-.098**	-.094**	-.314*	.239
Squash	.202	.245	-.519*	.102
Profession = Acquisition	-.024	.010	-.341**	-.130
Evaluation	-.029	-.087*	.243	.387**
Farming	.183**	.034	.098	.467**
Education	.110	.094	.545	-
Other	-.158**	-.198**	.165*	.174
Adjusted R2	.487	.499	.716	.752
n	1262	1135	79	48
F	71.547**	67.425**	9.064**	10.521**

Dependent variable is percentage of samples used in breeding program, still being evaluated, or useful in other ways; Weighted Least Squares Regression where weights are number of samples received by each respondent

* Significant at the 5% level; ** Significant at the 1% level; Notes: Crop omitted from the models = wheat; Profession omitted from the models = breeding;

Variables crop = rice, profession = education also omitted for the transitional economies model because of no observations.

In each model, the usefulness of samples was positively and significantly related to the usefulness of data for the trait of interest.²⁰ The models for developed countries and transitional economies also indicated that the percentage of material with other useful data was significantly and positively associated with the usefulness of samples (at the 1 percent and 5 percent levels, respectively), suggesting that the role of other useful data appears to be related to the level of income. We speculate that other useful data is likely to contribute to basic research (as well as breeding). This finding is consistent with greater levels of basic research found in higher income countries.

Within the model for developed countries, the variable GDP per capita was significant and negative, suggesting that respondents in richer countries were less likely to report that the germplasm samples were useful, as expected. The variable was not significant for the models of usefulness for respondents in developing countries or transitional economies, perhaps reflecting limited range in the variable and smaller subsample sizes.

Significant differences also emerged with respect to the specific crops received and the respondents' professions, though these varied by model. Relative to wheat (the omitted crop), the usefulness of barley, soybean or potato germplasm was lower in the developed country model, while the usefulness of cotton and rice were higher. Beans, maize, sorghum, and squash were not significantly different from wheat in this respect. For respondents in developing countries, the usefulness of barley, maize, soybean and squash materials were lower relative to wheat. For the transitional economies model, only beans differed significantly from wheat and, in this case, the usefulness was higher.

²⁰ The large relative magnitude of standardized coefficients (or z scores) in our model suggests that the variables measuring the usefulness of data are also the most important factors in the model.

Having respondents from one of the “other” professions resulted in a significantly different relationship with regard to the usefulness of materials, relative to breeding (the omitted category) within the developed country model. Respondents in other professions found samples less useful than did breeders. The profession of “evaluation” was also associated with a lower level of useful materials in that model. For the developing countries model, only respondents working in acquisition differed significantly from breeders, having lower levels of usefulness. For respondents in transitional economies, farmers and evaluators had higher levels of usefulness for their materials, though we do note that these categories accounted for a relatively small number of the respondents in this data set.

4. IMPLICATIONS FOR POLICY

Better information about the use of resources can guide resource allocation. Currently, the optimal distribution of genetic resources is unclear. The NPGS has a number of scientists serving on Crop Germplasm Committees and the Plant Germplasm Operations Committees who guide the set of activities for their crop (Clark et al 1997). The U.S. Government Accounting Office conducted a survey of these scientists, and asked them to rank different germplasm-related activities (GAO 1997). The activity given the greatest priority was acquisition of germplasm. In a dissenting view, Goodman (1990) stated that too much emphasis has been laid on acquisition and preservation, while evaluation, regeneration and utilization may be more important. Cox (2001) specifically noted that the lack of evaluation data has been a hindrance to using introduced germplasm in wheat breeding. The GAO survey suggested that the members of Crop Germplasm Committees are aware of these other needs. Three quarters of the committees stated that evaluation information is insufficient for crop breeding purpose. Still, the GAO report

stated that several NPGS officials see preserving germplasm viability as more fundamental in importance than information development and dissemination.

The results presented in this paper do not give a detailed answer to this dilemma either. However, our findings do provide information that helps better describe the NPGS' role for its users, and speaks to the importance of different services that it provides. These findings provide some additional information for difficult process of resource allocation. Concerning the value of genebanks, our results suggest the following:

1. *Demand for NPGS resources is substantial and comes from broad range of users.*

The volume of material distributed by the NPGS is the most eloquent evidence of demand for its services. For the ten crops studied in this paper alone, over 600,000 samples were distributed between 1990-1999, to fulfill recipients' requests. Public institutions, non-profits and commercial institutions requested, at a minimum, more than 100,000 samples each. Thus, not only do public and quasi-public institutions use the bank, but there is substantial use by private firms.

In addition to serving a range of institutions, the NPGS also provides germplasm to numerous countries. While U.S. requestors account for the majority of germplasm demand, the NPGS distributed germplasm to over 200 countries, territories, and departments and commonwealth association between 1990-1999. Volume is such that, for the ten crops studied in this paper, more than 150,000 samples were distributed to international requesters alone in the last decade.

While NPGS germplasm is used primarily for breeding and breeding-related activities, findings suggest that the system provides important resources for biological research, particularly basic biological research. The use of NPGS resources for research is particularly strong in the US. Given the returns to investments in basic research (Fuglie et al 1996), policymakers may want to consider the role the NPGS plays in supporting such research. Educators and people working in germplasm acquisition also make use of the NPGS resources, the latter more commonly among international users.

2. *Utilization rates are higher than expected.* One common criticism of genebanks is that their materials are rarely used. It has been suggested that these resources are primarily used when other options have failed, and that these “last ditch” efforts have low probabilities of success. Given the lengthy and serendipitous nature of breeding, this seems a reasonable assumption. However, the NPGS users of 10 important crops indicate otherwise. Respondents stated that nearly half the materials received from the NPGS had already been used in breeding programs, had been considered worthy of further evaluation, or had been useful in other ways. Estimates of actual use suggest that more than 25,000 samples have already been used in a breeding program. Secondary use through sharing within and outside respondents’ institutions implies additional use not captured in our numbers.

3. *Accompanying data make germplasm more useful.* While in theory data could aid the research and breeding process, empirical evidence on supplementary data and the value of public germplasm has been lacking. We estimated a regression model using responses from NPGS users to test the association between data and germplasm use. Results confirm that samples with useful data were associated positively with use in breeding programs, continued evaluation, or other kinds of respondent-assessed usefulness. These results hold both for data for the trait of interest, and for other useful data. Further research that explores types of data, and their relative usefulness, is warranted.

4. *Most germplasm does not come with useful data, but is still demanded.* While the data accompanying samples increases their usefulness, it does not appear to be a necessary component for germplasm demand. The Germplasm Resources Information Network (GRIN) web server provides germplasm information, including characterization and evaluation data. Thus, requestors have an opportunity to see what data are available for a given accession. Within the descriptor area of the search function, evaluation and characterization data queries are offered. Requestors can screen for such attributes as resistance and agronomic traits. Nonetheless, the majority of germplasm received by respondents did not include useful data either for the trait of interest, or other useful data. Offering additional accessions with

information might increase demand for that germplasm, but demand appears strong independent of the data element. Thus, a lack of data does not negate germplasm demand.

5. *While the U.S. accounts for most requests, developing countries make more intensive use of NPGS resources, relatively speaking.* Developing countries constitute a significant portion of international demand for NPGS resources. Samples distributed to developing countries exceeded those distributed to developed or transitional economies outside the U.S. More importantly, respondents in developing countries already had used a much higher percentage of germplasm received from the NPGS in breeding programs, and were evaluating still more. Respondents in developing countries were more likely to share germplasm with colleagues, thus contributing to secondary use of NPGS resources. In fact, we estimate that recipients in developing countries account for 70 percent of secondary transfers of NPGS germplasm, internationally. The fact that NPGS materials are provided free of charge gives scientists in many countries access to a range of resources that they might not be able to use otherwise, and these resources are being used productively.
6. *Demand for NPGS resources is likely to increase.* While the demand for NPGS resources during the 1990s is an important indicator of use of the system, respondents directly gave their expectations of future use. Nearly half the respondents expected their demand for NPGS germplasm to stay the same (47 percent). Of those expecting their demand to change, twice as many respondents expected their demand to increase rather than decrease. The expectation of increased future use was particularly high among respondents in countries whose demand, in terms of samples distributed, was highest among international users of the system. The greatest decrease was expected among respondents who are not affiliated with any institutions and who have demanded relatively less germplasm in terms of the numbers of samples. Therefore, within the context of the ten crops of this study, it appears likely that demand for NPGS resources will increase overall.

7. *Ownership.* Concerning the debate over ownership, one of the primary points of contention in the international exchange of genetic resources has been the perceived equity (or inequity) of the use and benefits of germplasm. Any judgments on the merits of such arguments are beyond the scope of this paper. However, information on usefulness of NPGS germplasm, secondary sharing, and future use expectations may be useful in gauging the benefits of the NPGS system for different users.

The demand seen for landraces and wild relatives suggests that indigenous resources continue to be of interest to breeders and scientists in countries at all levels of development. Still, the majority of materials requested were cultivars, advanced materials, or genetic stocks, all of which have resulted from some modern breeding or scientific efforts. Respondents, regardless of the development status of their country, made use of all types of germplasm and generally expected to continue to do so, providing further indication of the interdependence of nations with respect to germplasm.

As noted before, the NPGS offers its resources free of charge. The expectation that this will continue probably contributed to respondents' expectations of their future demand. The new International Treaty on Plant Genetic Resources for Food and Agriculture contains provisions for the sharing of benefits from commercialized products resulting from germplasm provided through the multilateral system. These benefit-sharing provisions would affect germplasm distributed through the NPGS. At the time of this writing, however, the terms of the standard Material Transfer Agreement are unclear. They are likely to involve some form of payment to the Multilateral System upon sale of a commercial product. This has the potential to dissuade private use of NPGS resources. The most likely products to be subjected to benefit sharing would be crops with large markets and significant private market breeding activities. Maize is possibly one such crop, as are cotton and soybean. We note, however, that much of the demand for maize germplasm actually stems from basic research. Given the likelihood of an exemption

from benefit sharing provisions for those products that are available for research purposes, it is not clear that the benefit sharing provisions will dampen demand for NPGS products. This is particularly true with developing country users. Realistic expectation about the possible returns from benefit sharing would help this process. The level of payment required will be crucial in determining demand for public germplasm. Should the payment be deemed unreasonable or unaffordable by private companies, they will avoid using materials from the multilateral system, thus defeating the goals of benefit sharing. This is particularly true of private companies with narrow profit margins, such as those dealing with minor crops, crops with limited appropriability, and crops adapted to low-income agricultural areas.

While the mechanics of future germplasm exchange remain uncertain, the overall picture from this study of the NPGS is one of a system providing a valued range of specialized materials to a broad range of users. Moreover, these materials appear to be remarkably useful in actual practice.

**Appendix 1--Countries, territories, departments, or commonwealth associations receiving
germplasm samples from U.S. NPGS, 1995-1999**

Country	Classification	Country	Classification
Algeria	Developing	Lesotho	Developing
Angola	Developing	Liberia	Developing
Anguilla	Developing	Lithuania	Transitional
Argentina	Developing	Macedonia	Transitional
Australia	Developed	Malawi	Developing
Austria	Developed	Malaysia	Developing
Bahrain	Developing	Mali	Developing
Barbados	Developing	Mayotte	Developing
Belarus	Developing	Mexico	Developing
Belgium	Developed	Moldova	Transitional
Bolivia	Developing	Namibia	Developing
Brazil	Developing	Netherlands	Developed
Brunei	Developing	New Zealand	Developed
Bulgaria	Transitional	Nigeria	Developing
Canada	Developed	Norway	Developed
Chad	Developing	Pakistan	Developing
Chile	Developing	Peru	Developing
China	Developing	Philippines	Developing
China	Developing	Poland	Transitional
Colombia	Developing	Portugal	Developed
Costa Rica	Developing	Puerto Rico	developing
Cote D'Ivoire	Developing	Romania	Transitional
Croatia	Transitional	Russian Federation	Transitional
Czech Republic	Transitional	Rwanda	Developing
Denmark	Developed	Saudi Arabia	Developing
Ecuador	Developing	Sierra Leone	Developing
Egypt	Developing	Slovakia	Transitional
Estonia	Transitional	Slovenia	Transitional
Ethiopia	Transitional	South Africa	Developing
Finland	Developed	Spain	Developed
France	Developed	St. Vincent and Grenadines	Developing
Georgia	Transitional	Sudan	Developing
Germany	Developed	Sweden	Developed
Ghana	Developing	Switzerland	Developed
Greece	Developed	Syria	Developing
Guatemala	Developing	Taiwan	Developing
Haiti	Developing	Tanzania	Developing
Honduras	Developing	Thailand	Developing
Hong Kong	Developing	Thailand	Developing
Hungary	Transitional	Trinidad and Tobago	Developing
India	Developing	Tunisia	Developing
India	Developing	Turkey	Developing
Indonesia	Developing	Uganda	Developing

**Appendix 1--Countries, territories, departments, or commonwealth associations receiving
germplasm samples from U.S. NPGS, 1995-1999 (continued)**

Ireland	Developed	Ukraine	Transitional
Israel	Developed	United Kingdom	Developed
Italy	Developed	Venezuela	Developing
Japan	Developed	Vietnam	Developing
Korea, South	Developing	Yugoslavia	Transitional
Kuwait	Developing	Zambia	Developing
Latvia	Transitional		

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